



# High pressure gas TPC in the DUNE beamline

George Christodoulou

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UNIVERSITY OF  
LIVERPOOL

# Overview

- Benefits of high pressure (HP) gas TPC
- Updates of the HP gas TPC simulation
  - Initially developed by T. Stainer *et al* for LBNO
    - <https://dpnc-indico.unige.ch/indico/getFile.py/access?resId=0&materialId=1&confId=354>
  - Adopted and improved for DUNE
- First simulation results
  - Event rates
  - Signals and backgrounds

# Benefits of HP gas TPC

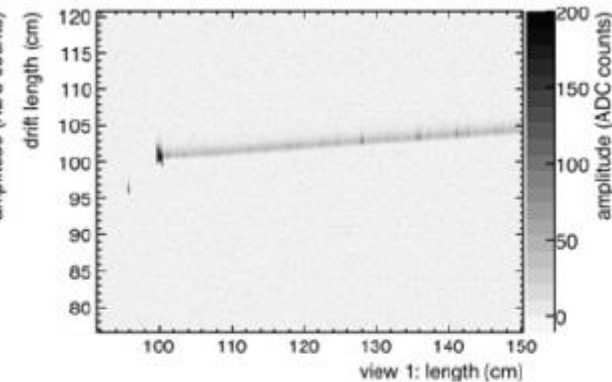
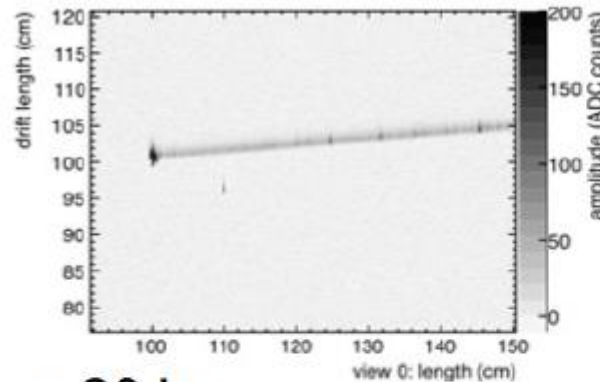
- Magnetized and  $\sim 4\pi$  coverage
- Same target as the DUNE far detector
- Pressure and target flexibility
  - He, Ne, Ar, CF<sub>4</sub> can be used to study A-dependence and FSI
- Excellent PID
- Low density and low thresholds
  - Sensitivity to  $< 100$  MeV/c protons and  $< 25$  MeV/c muons and pions
  - Model testing and generator tuning
    - 2p2h, spectral functions, FSI
    - $1\pi$  and high mass resonance

# Detection of soft tracks in HP TPC

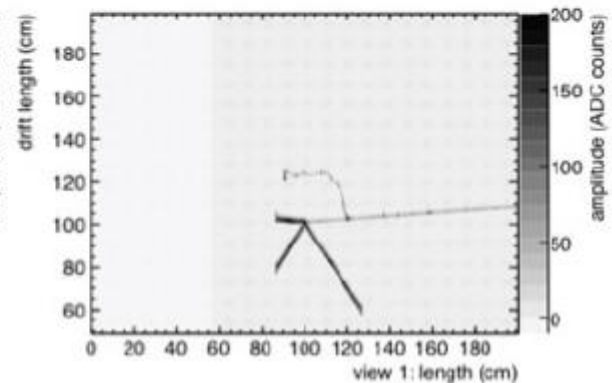
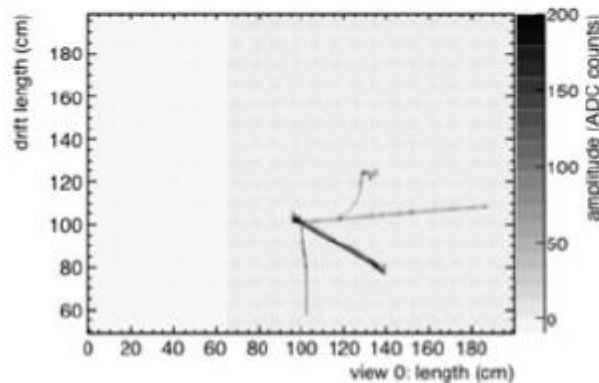
- Soft protons can be undetectable in LAr

liquid Ar

A. Curioni, T. Stainer

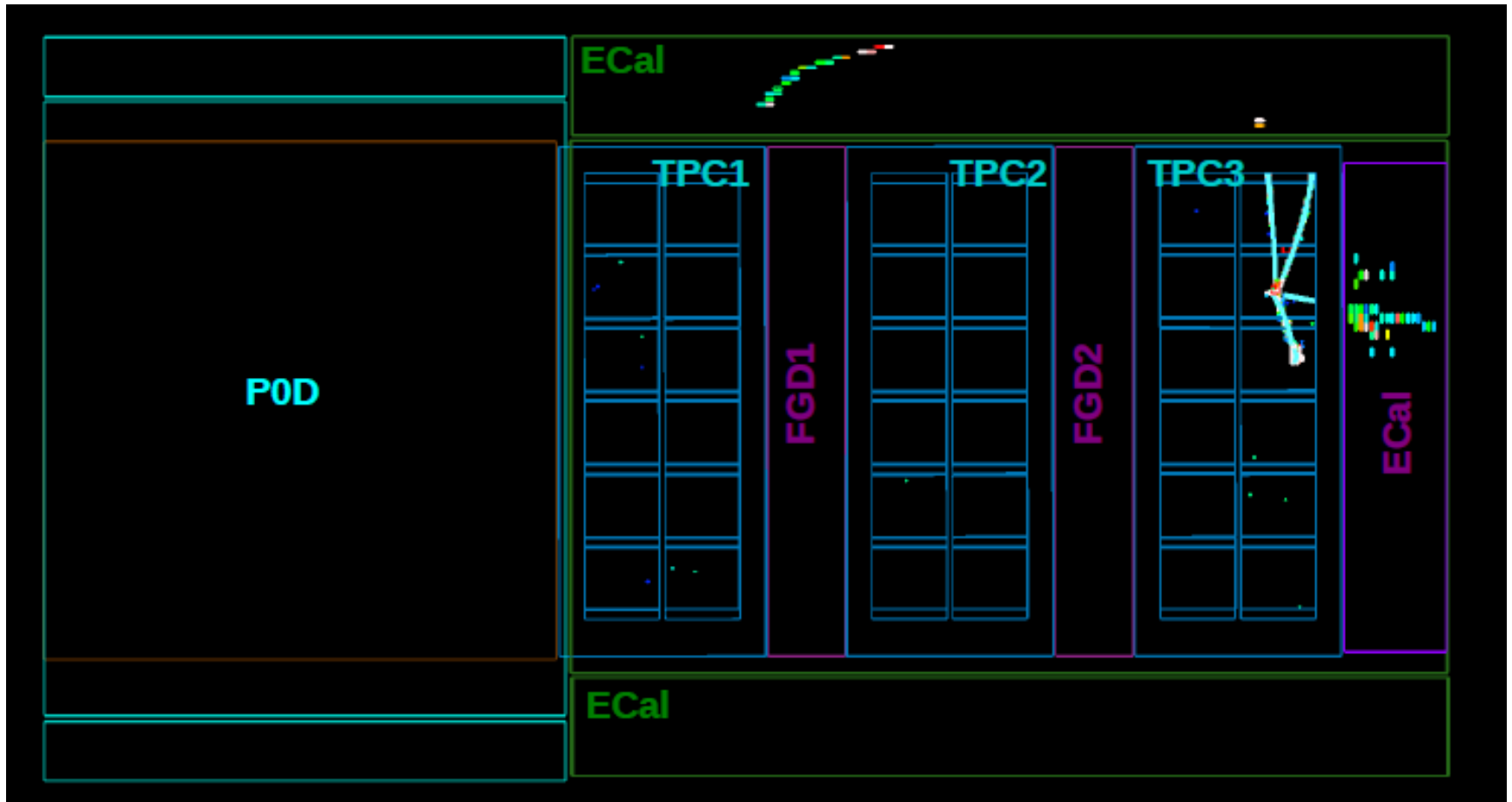


Ar gas 20 bar

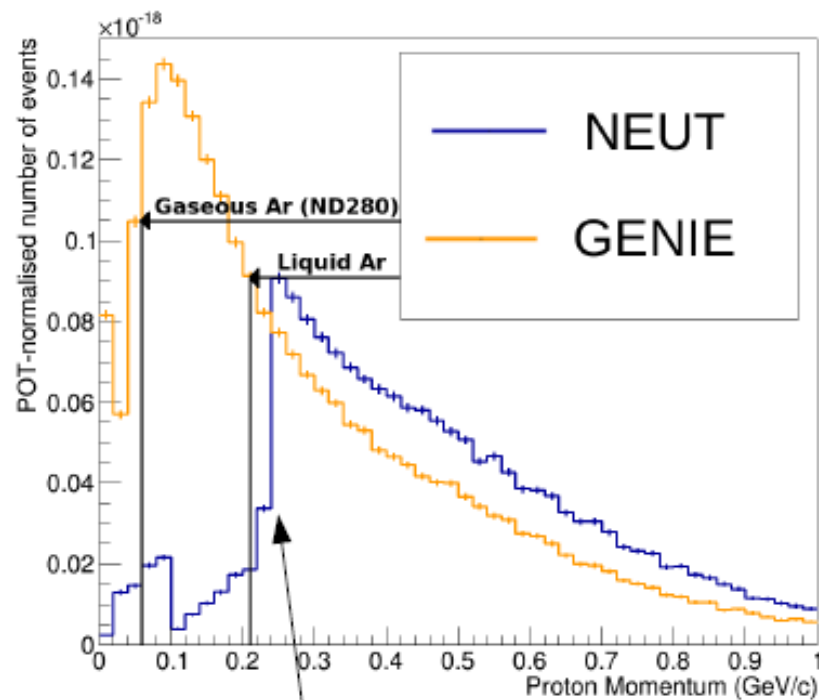


# Gas TPC neutrino event in T2K near detector

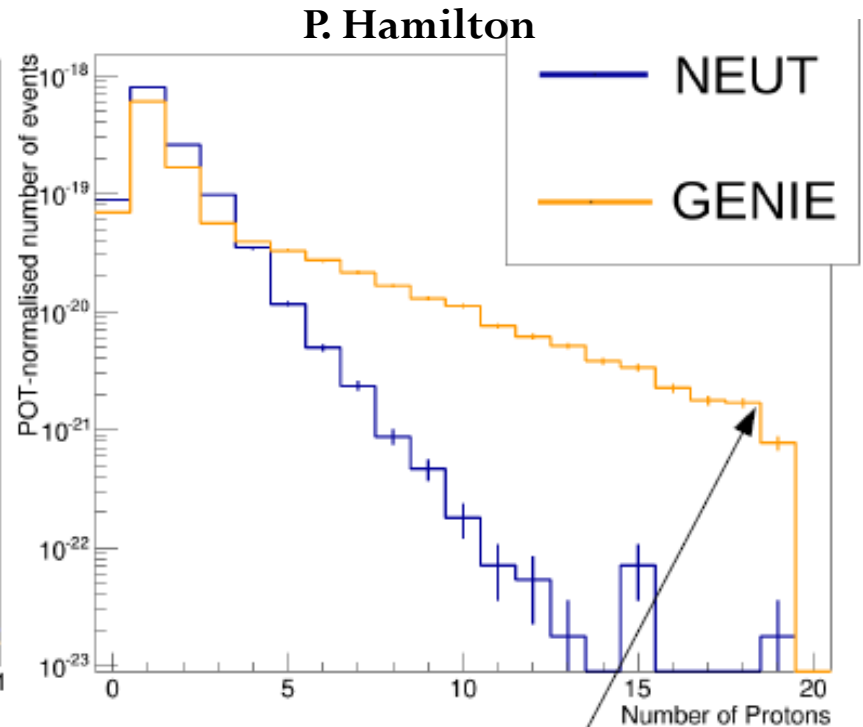
P. Hamilton



# Low energy sensitivity in gas TPC – example from T2K near detector

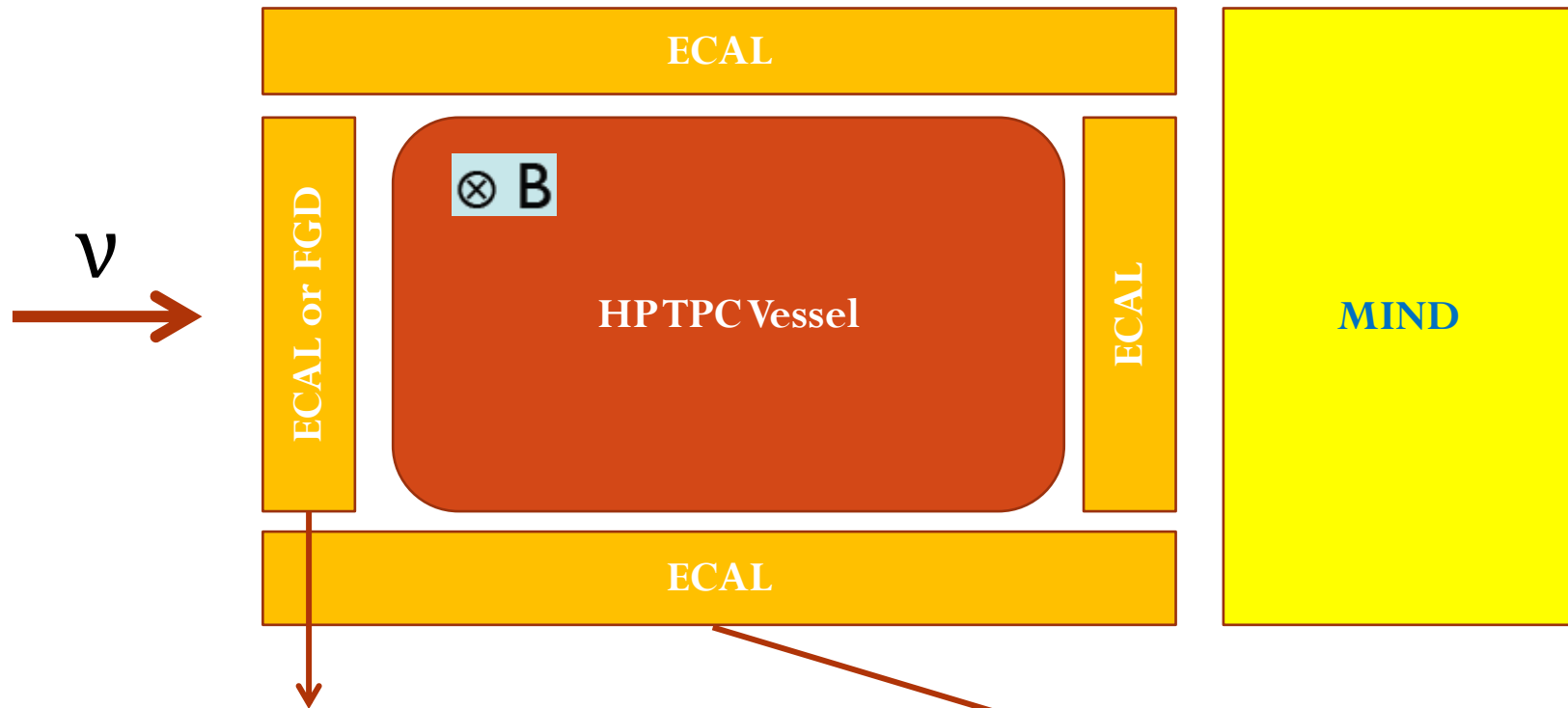


Fermi momentum "cliff"



Ludicrous GENIE multiplicity tail!

# Basic design of the HP TPC for DUNE



Could also be another target for neutrino interactions

HPTPC is surrounded by the ECAL for neutral particle containment  
ECAL can provide additional target for neutrino interactions  
ECAL inside the vessel is another (challenging) possibility

# HP TPC simulation for DUNE

- Near detector located 459m from the target
- Test and debugging production of  $1.5 \times 10^{19}$  POT for forward horn current (FHC)
- Flux files provided by Laura Fields
  - “Nominal” beam simulation version v3r3p5 at 200kA
- Simulate only the HP TPC gas volume and the vessel
  - Flux+Genie+Geant4
    - Code in <https://github.com/DUNE/wp1-neardetector>
  - $4.0 \times 4.0 \times 4.0$  m
  - 20 bar,  $\sim 550$  kg,  $0.035 \text{ g/cm}^3$
  - $\sim 35\text{k events} / 1.5 \times 10^{19}$  POT in the gas volume
  - $\sim 10$  times more events in the 10 cm thick aluminium vessel
    - 70% give some activity in the HPTPC



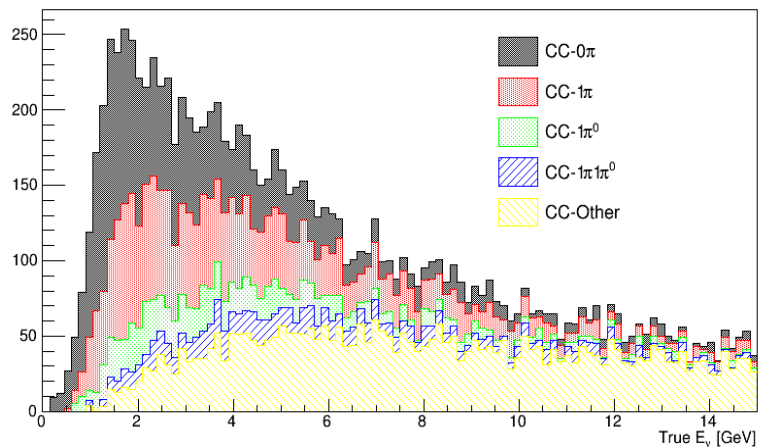
# Neutrino interactions for FHC in the HP TPC

Primary state topology	%
$\nu_\mu$ CC- $0\pi$	9.4
$\nu_\mu$ CC- $1\pi^\pm$	15.0
$\nu_\mu$ CC- $1\pi^0$	4.9
$\nu_\mu$ CC- $1\pi^\pm 1\pi^0$	4.4
$\nu_\mu$ CC-Other	30.5
NC	25.0
$\bar{\nu}_\mu$ CC	8.3
$\nu_e$ - $\bar{\nu}_e$ CC	2.2

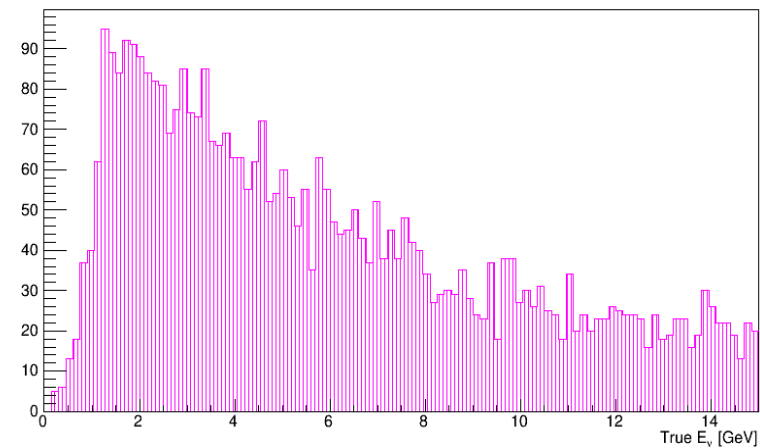
$\nu_\mu$ interaction	%
CC-QEL	10.5
CC-RES	28.5
CC-DIS	35.9
CC-COH	0.4
NC-QEL	3.7
NC-RES	9.5
NC-DIS	11.3
NC-COH	0.2
Other	<0.1

# FHC true topology

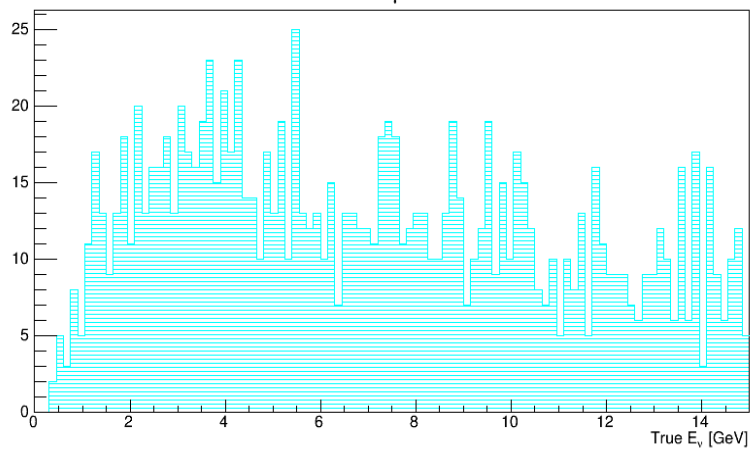
$\nu_\mu$



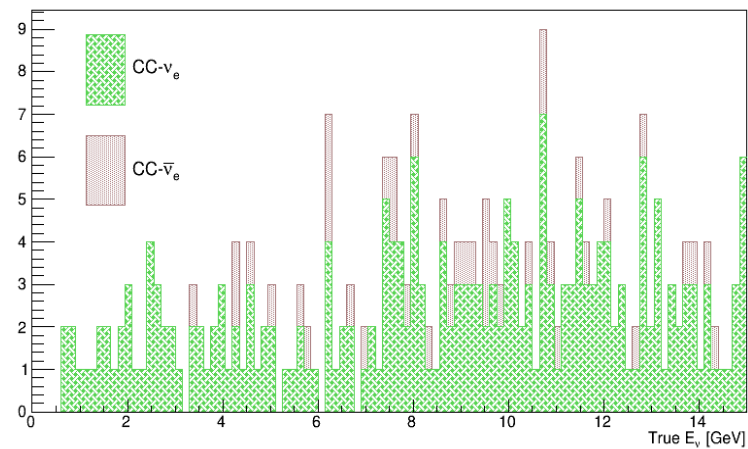
NC



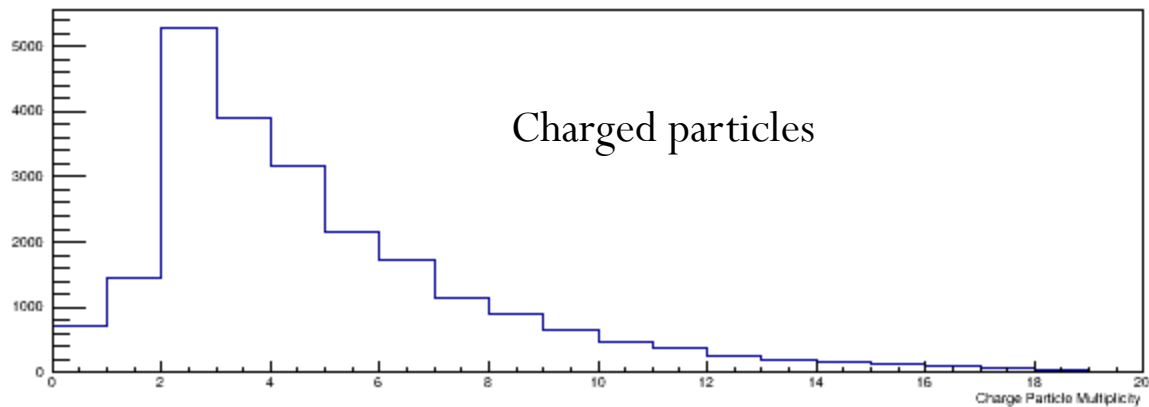
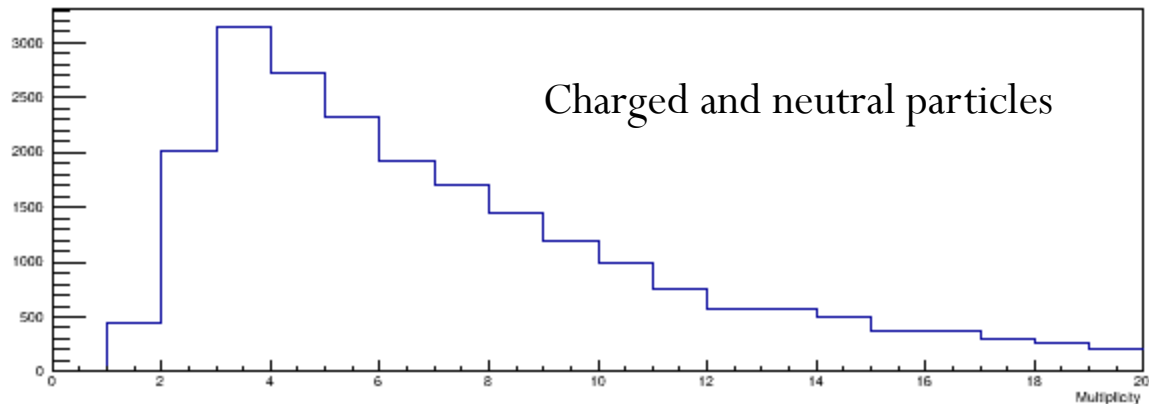
$\bar{\nu}_\mu$



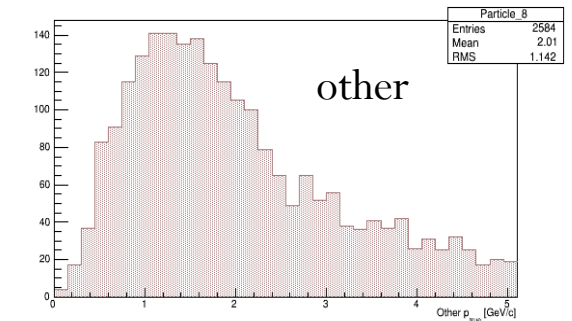
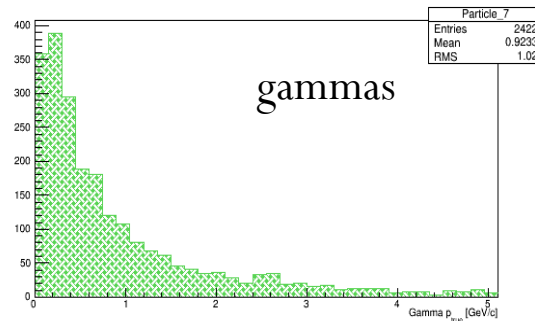
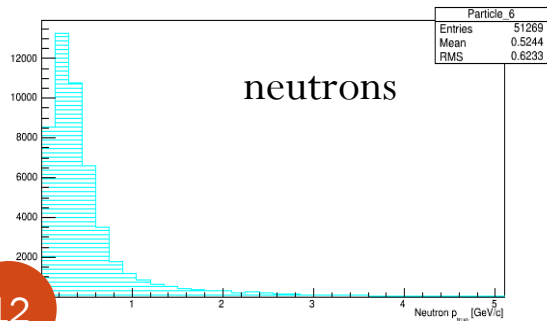
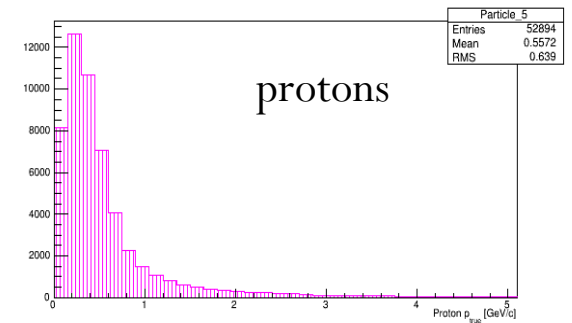
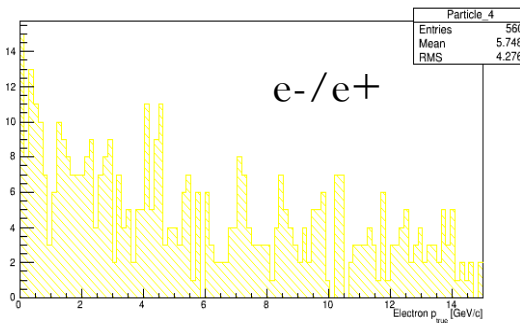
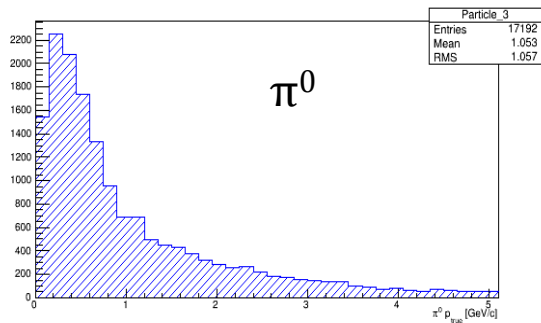
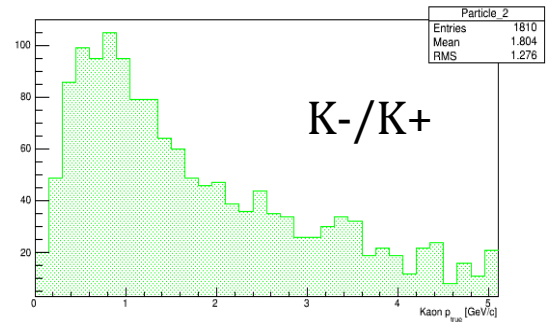
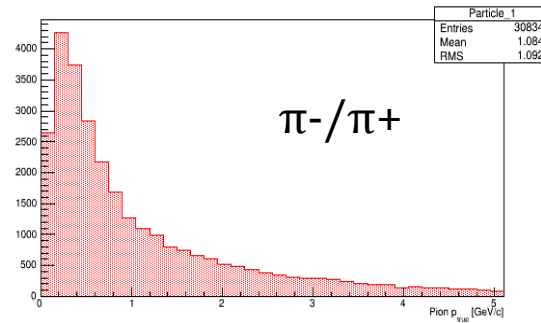
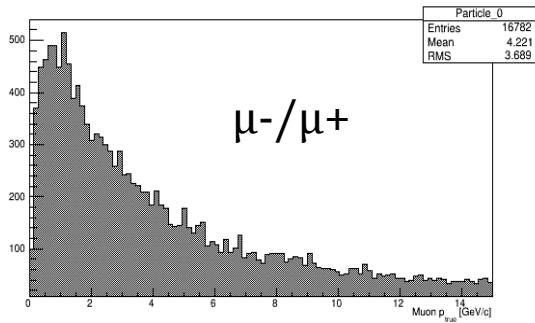
$\nu_e$



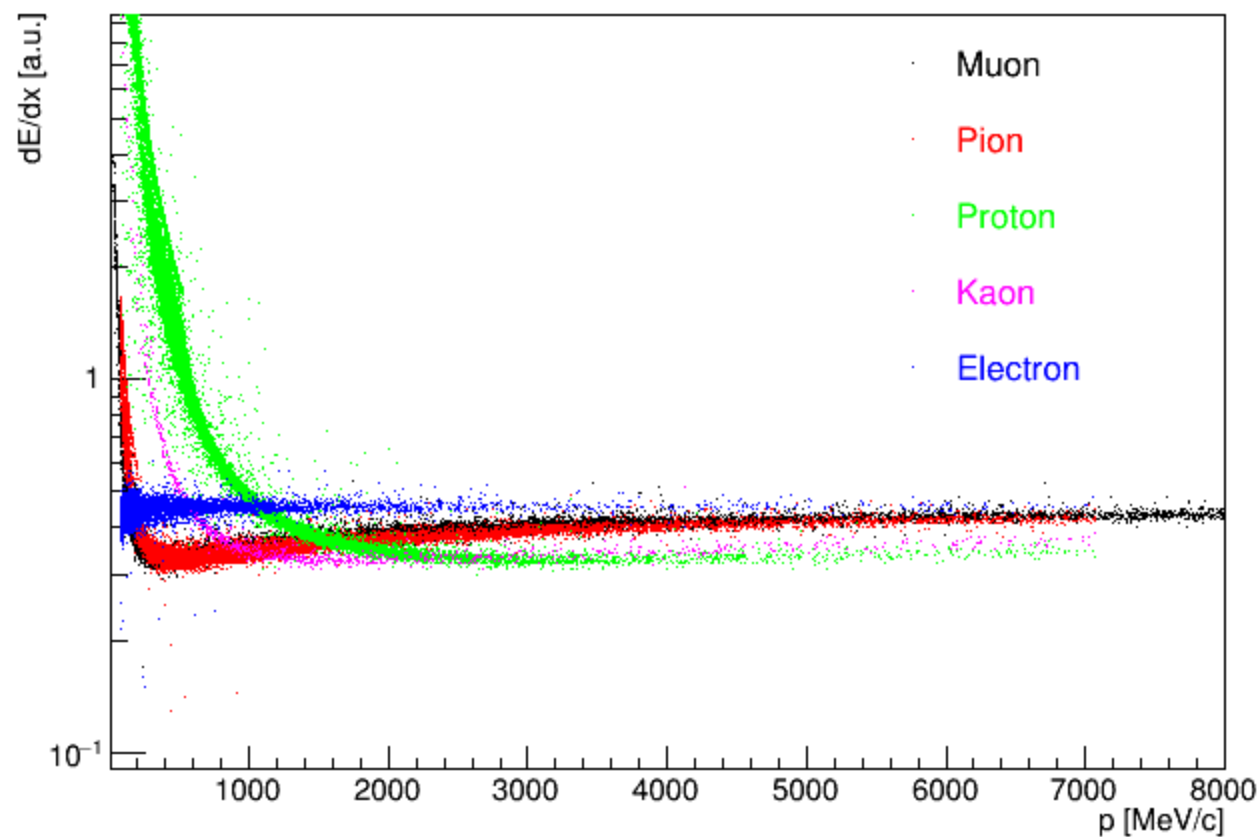
# Multiplicity at the generator level



# Momentum distributions at the generator level



# $dE/dx$ in the 20 bar HP TPC

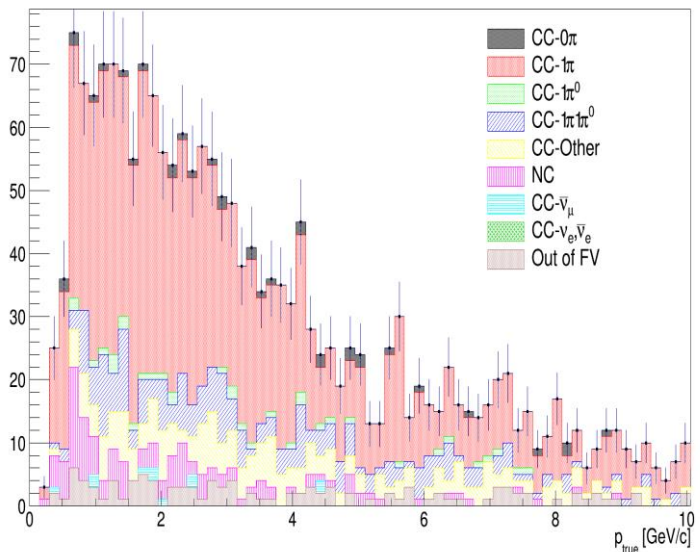


# Pile-up in the near detector

- For every 1 neutrino interaction in the HP TPC Ar Gas
  - $\sim 10$  neutrino interactions in the vessel (from simulation)
  - $\sim 125$  neutrino interactions in the ECAL (estimated)
    - Assuming 30cm pure scintillation detector
  - $\sim 625$  neutrino interactions in the magnet (estimated)
    - Assuming 50cm iron
- Challenges
  - Veto against charged particle tracks coming outside the HP TPC volume
  - Reconstruction of ECAL neutral clusters

# Preliminary example of event selection in the HP TPC – CC1 $\pi^\pm$

- Preliminary event selection – not optimized
  - Fiducial volume box reduced by 70cm from the HP TPC box in all directions
  - Track length > 25 cm
  - $P > 25 \text{ MeV}/c$
  - Highest momentum track is  $\mu^-$  or  $\pi^-$
  - Only one  $\pi^\pm$
  - No tracks starting > 15cm from the vertex

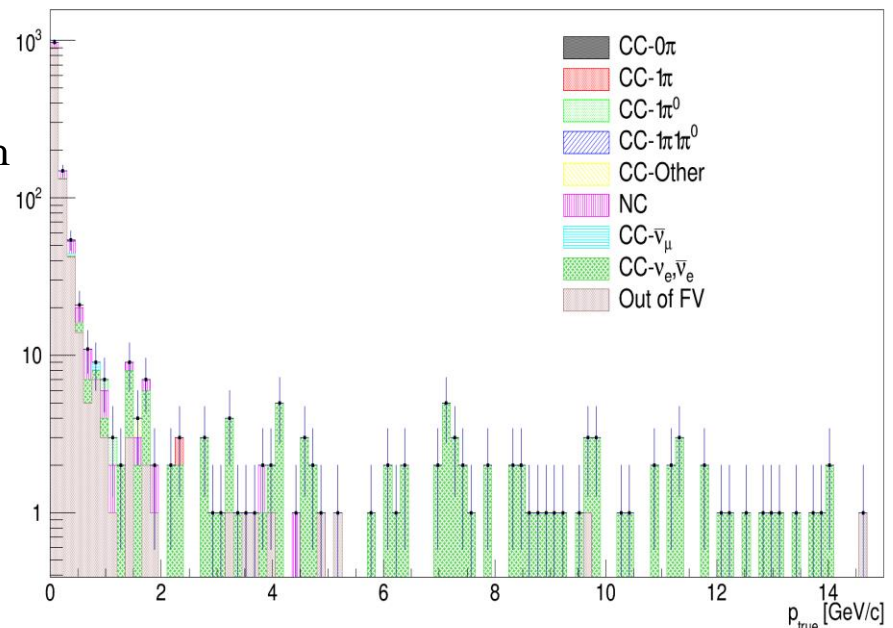


Events / $1.5 \times 10^{19}$ POT	Efficiency (%)	Purity (%)	Events with a FS $\pi^0$ (%)
2315	22.7	59.6	24.5

# Preliminary example of event selection in the HP TPC - CC- $\nu_e$ inclusive

- Preliminary event selection – not optimized
  - Fiducial volume box reduced by 70cm from the HP TPC box in all directions
  - Track length  $> 25$  cm
  - $P > 25$  MeV/c
  - Highest momentum track is  $e^-$
  - No other  $e^-/e^+$  tracks
  - No tracks starting  $> 15$ cm from the vertex
- $\pi^0$  induced background dominated near the 1<sup>st</sup> and 2<sup>nd</sup> oscillation maximum
- Need more careful studies

Events / $1.5 \times 10^{19}$ POT	Efficiency (%)	Purity (%)
1368	21.6	9.3





# Summary and future plans

- HP TPC provides an opportunity to detect vertex activity beyond the sensitivity of LAr detectors
- First version of the HP TPC simulation for DUNE has been developed
- Preliminary results look promising
- Next steps
  - New MC production of  $10^{20}$  FHC POT with updated flux files available soon
  - Introduce reconstruction efficiencies and PID
  - Understand signal and backgrounds
  - Deal with the pile-up from neutrino interactions outside the HP TPC volume
  - Start thinking about the ECAL
    - Optimum design, technology etc

# Back up

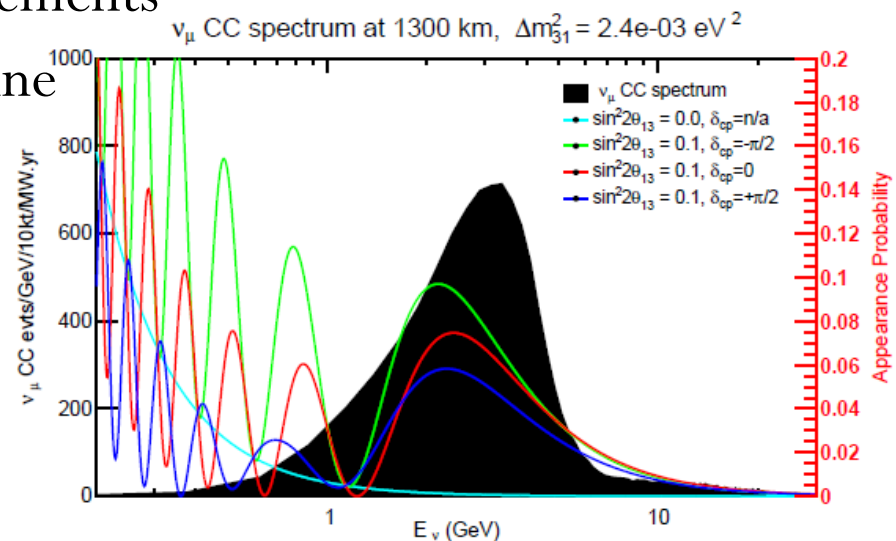
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# The new FNAL flux files

- DUNE uses a different flux n-tuple than the other Fermilab experiments
  - Flux files have to be converted to the new flux file format (Dk2nu)
  - At the moment this is only possible by obtaining the Dk2nu package
    - Later Genie releases will have this implemented
  - Change the beam window in GNUMIFlux.xml
  - Run the new `gevgen_fnal` or `gevgen_numi` from Dk2nu

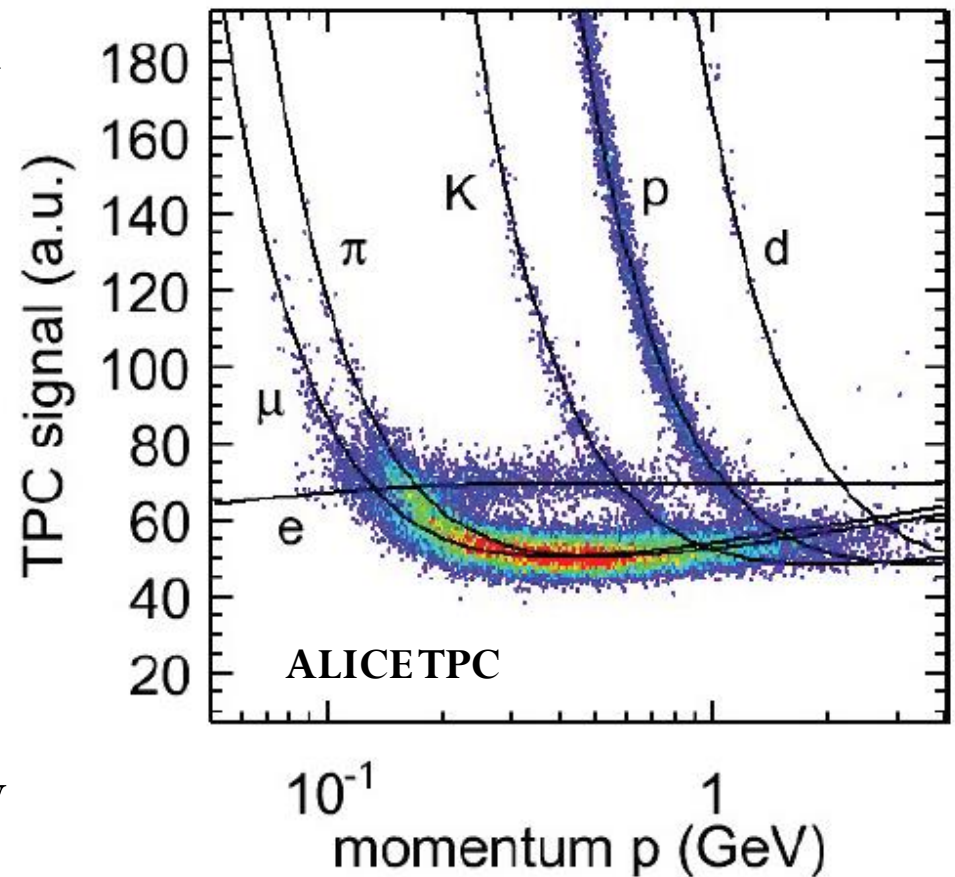
# The role of near detector for DUNE

- Constrain the systematic uncertainties for the neutrino oscillation measurements
  - Select various inclusive and semi-inclusive samples for all neutrino species
  - (Anti-)Neutrino energy scale
  - Background channels for the oscillation analysis ( $\pi^0$ , etc)
  - Cover first and second oscillation maximum
- Neutrino cross section measurements
- New physics in the short baseline

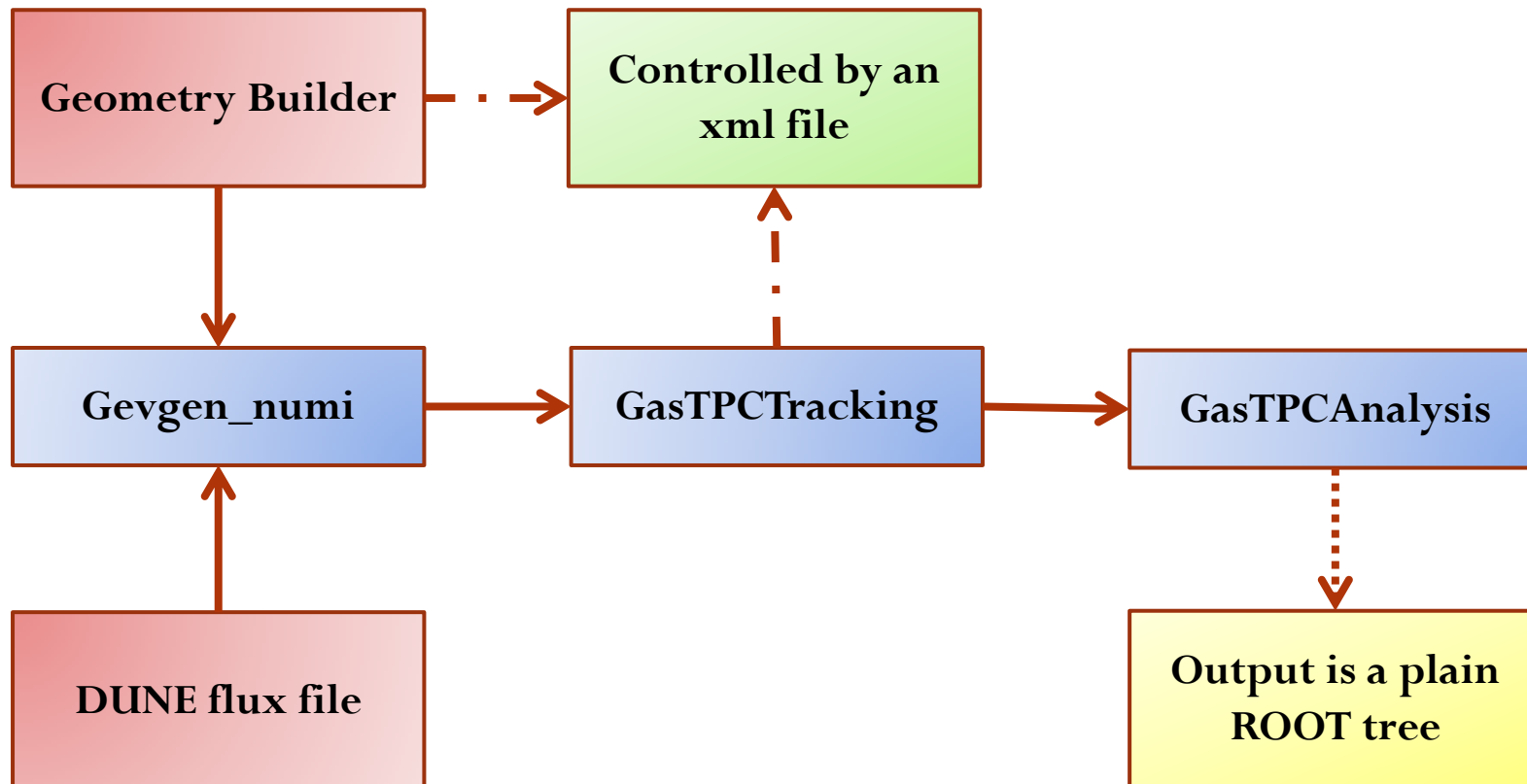


# Particle identification using $dE/dx$

- Proven technology, well understood used for many years
- Advantages
  - Excellent PID in a broad momentum range
  - Very good momentum resolution
- Disadvantages
  - No muon-pion separation
  - Regions where the energy loss curves cross

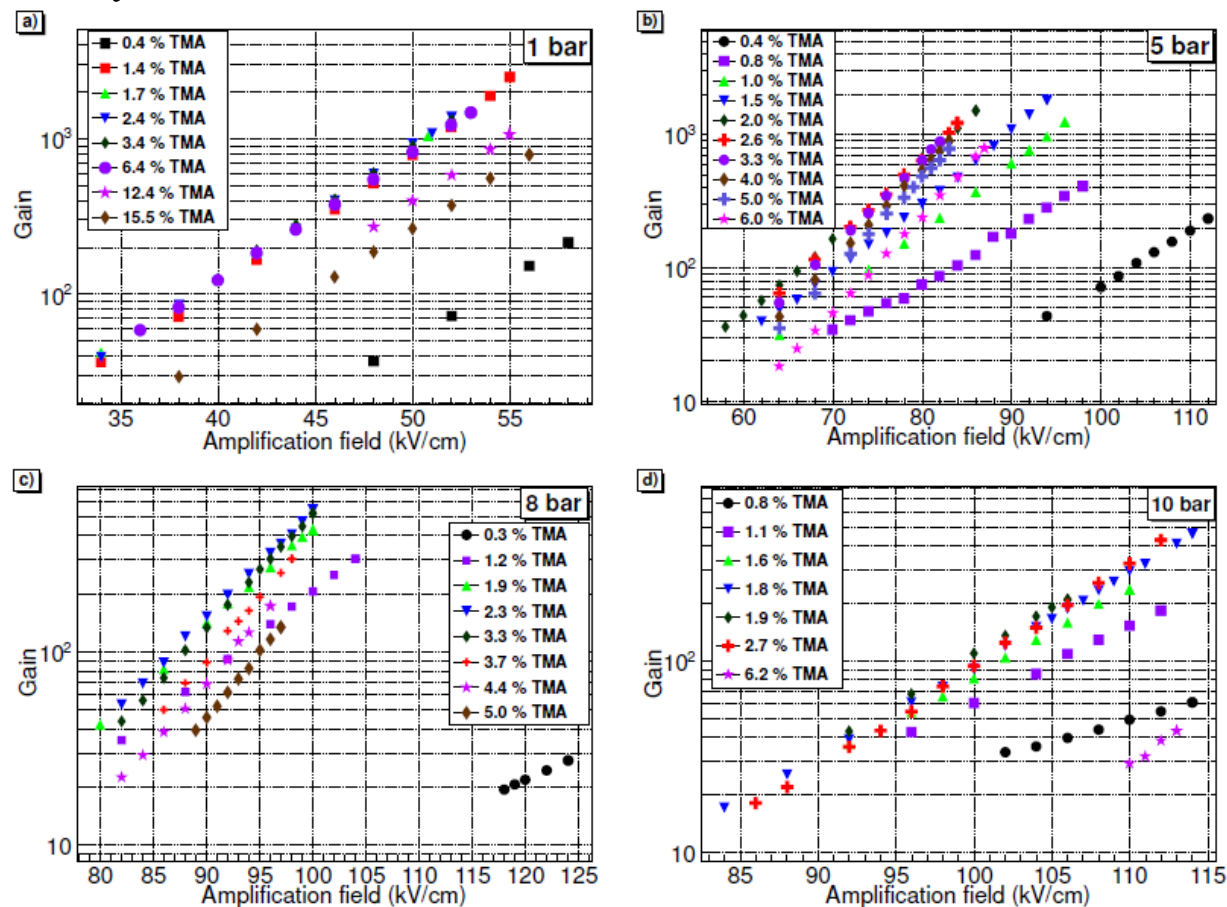


# How to run the simulation using realistic flux and geometry



# High pressure gas gain

- Micromegas-TPC operation at high pressure in xenon-trimethylamine mixtures (arXiv:1210.3287)



# HP TPC $T_0$

- Need to determine  $t_0$  for the time co-ordinate
  - Use the ECAL
    - Issue with low energy tracks
  - Light emitted during ionization
    - PMTs inside the detector
    - Gas mixture light absorption
    - Wavelength  $< 128$  nm
  - Transverse diffusion
    - Number of channels